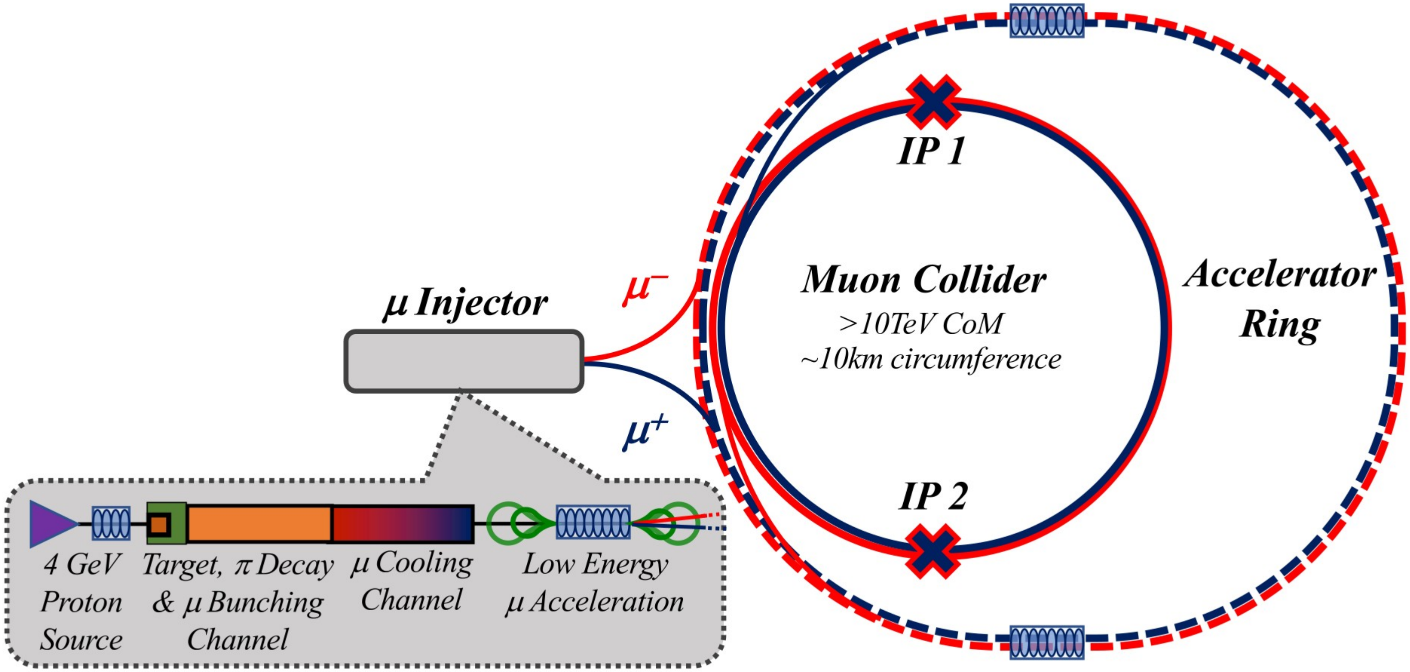
Rectilinear Cooling Channel Status

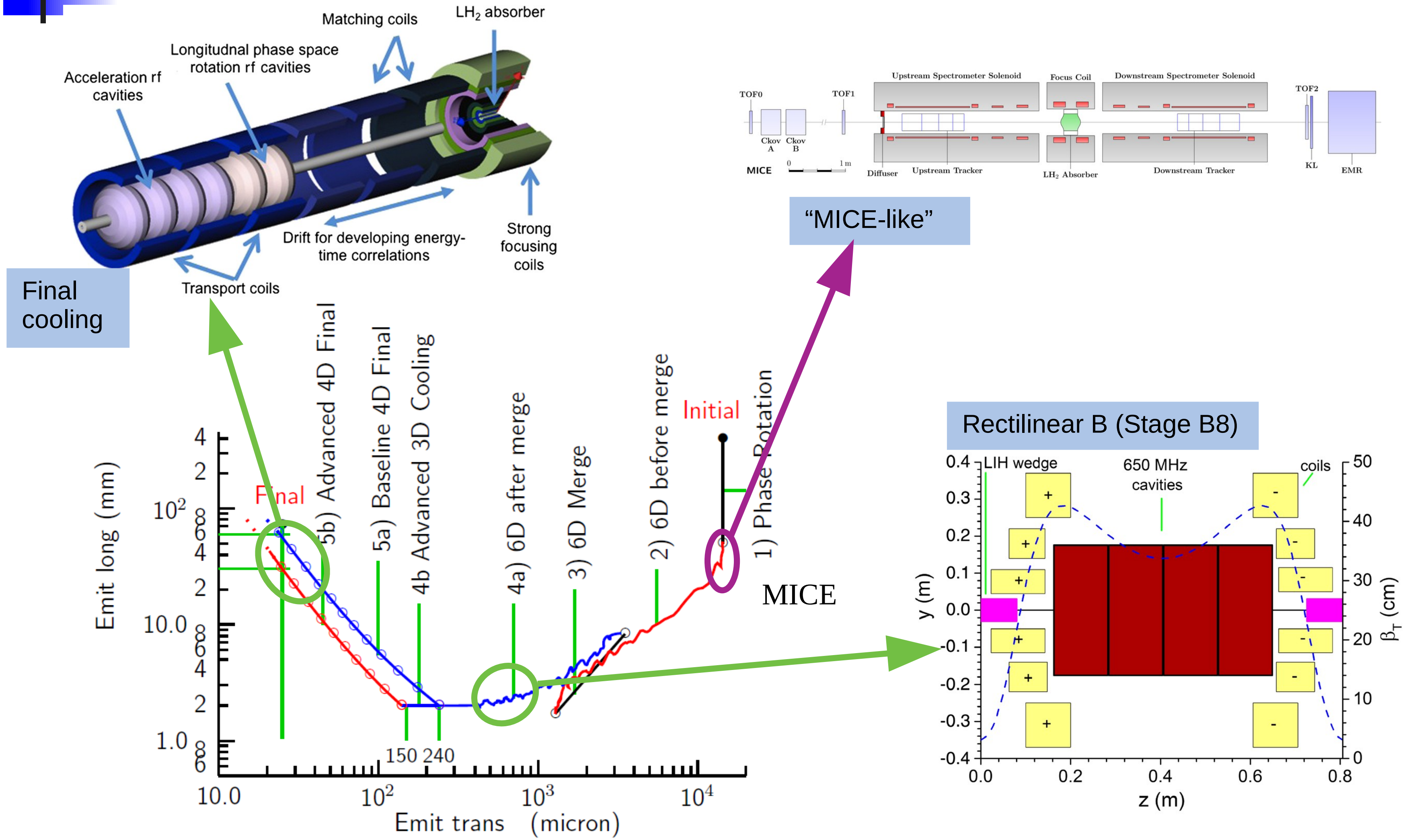
C. T. Rogers
ISIS
Rutherford Appleton Laboratory

Rectilinear cooling



- Muons created at the target have a huge emittance
  - Need to cool the muon beam
- Conventional cooling techniques are too slow
  - Use ionisation cooling – fast but novel technology

Cooling for a Muon Collider



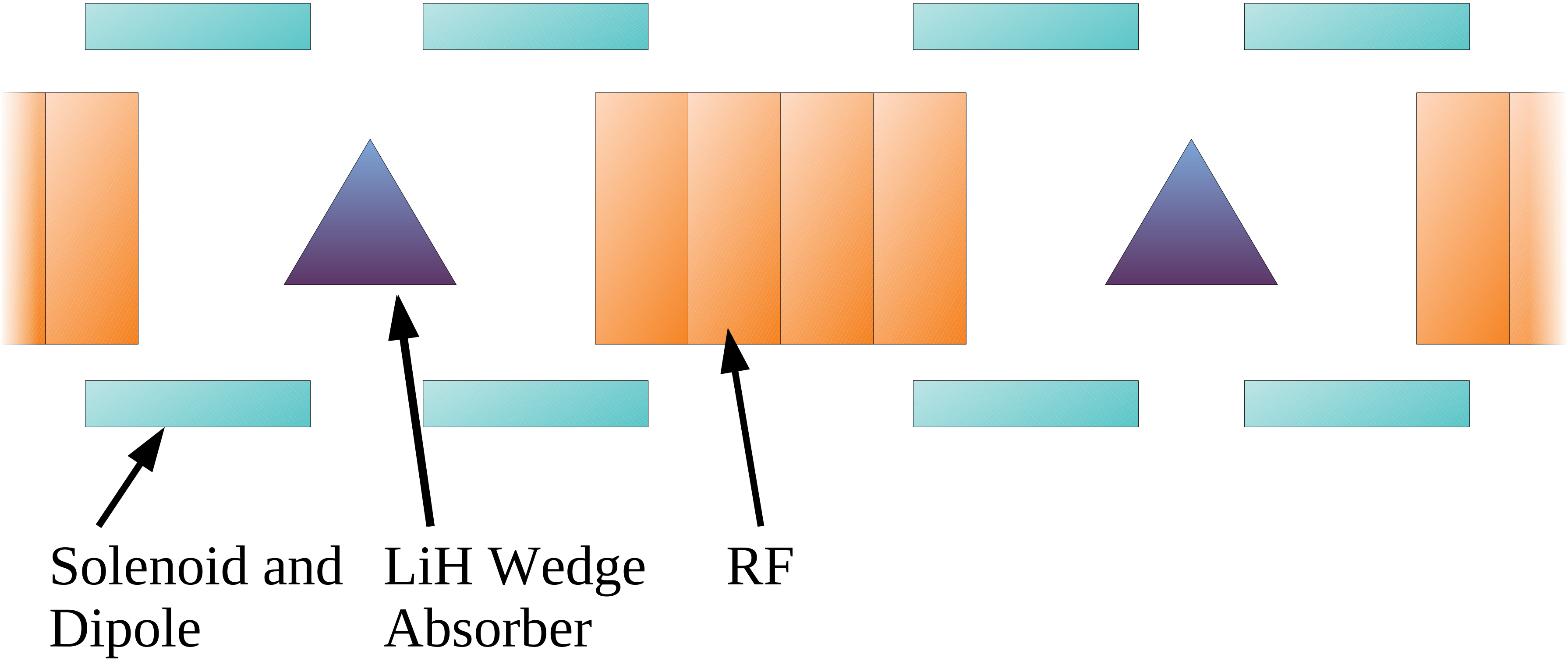
Final cooling

“MICE-like”

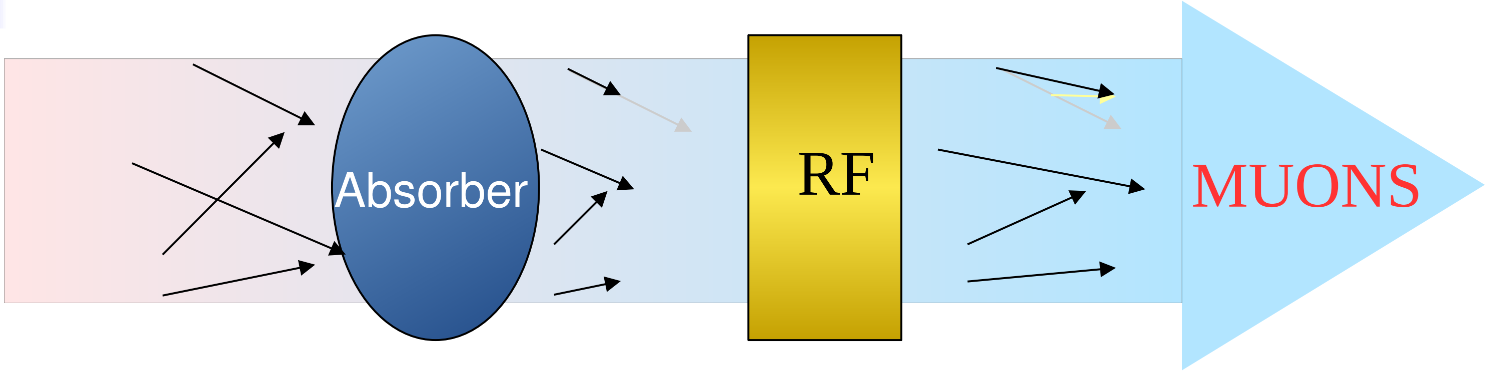
Rectilinear B (Stage B8)

Rectilinear Cooling Channel

- Rectilinear cooling channel
  - Aim to reduce transverse and longitudinal emittance
- Reminder:

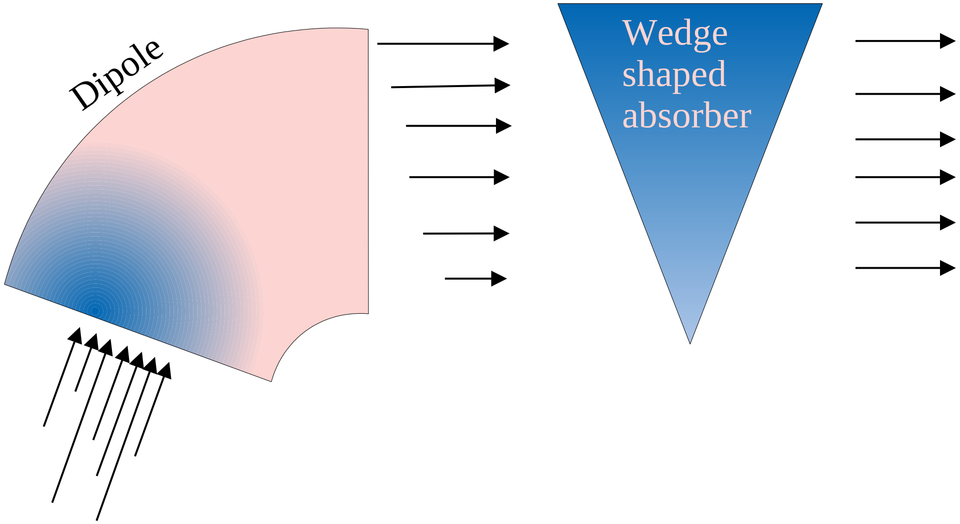


Ionisation Cooling



- Beam loses energy in absorbing material
  - Absorber removes momentum in all directions
  - RF cavity replaces momentum only in longitudinal direction
  - End up with beam that is more parallel
- Multiple Coulomb scattering from nucleus ruins the effect
  - Mitigate with tight focussing → low β
  - Mitigate with low-Z materials
  - Equilibrium emittance where MCS cancels the cooling
- Verified by the Muon Ionisation Cooling Experiment (MICE)

6D Ionisation Cooling



- Initial beam is narrow with some momentum spread
  - Low transverse emittance and high longitudinal emittance
- Beam follows curved trajectory in dipole
  - Higher momentum particles have higher radius trajectory
  - Beam leaves dipole wider with energy-position correlation
- Beam goes through wedge shaped absorber
  - Beam leaves wider without energy-position correlation
  - High transverse emittance and low longitudinal emittance
- Tests done at Fermilab

Job List (Simulation oriented)

- Full list to get to CDR (some stuff will not be done by 2026)
- Beam physics design
  - Basic design, including tapering, understanding dynamic aperture, matching – **EU milestone Dec 23**
  - Alignment and tolerances
  - Collimation systems and radiation protection
  - Uncontrolled losses on SC magnets and other equipment
  - Liaison with RF and magnets
- Collective effects
  - Beam loading
    - Effect of beam loading for each cell
    - Investigate mitigation, together with RF team
  - Effect of space charge on the cooling cell simulation and appropriate mitigations
  - (Absorber heat load on next slide)
- Code preparation
  - BDSIM – **EU deliverable Jan 25**
  - Others

Job List (Hardware oriented)

- Beam instrumentation
  - System design to measure beam profile, time and energy spread
- Absorber design
  - With an eye to heat loads, radiation load and appropriate mitigations. Possible consideration of active cooling system
- Engineering integration
  - Integration of magnets and RF
  - Alignment system
  - Integrated thermal design
  - Vacuum systems

Specification

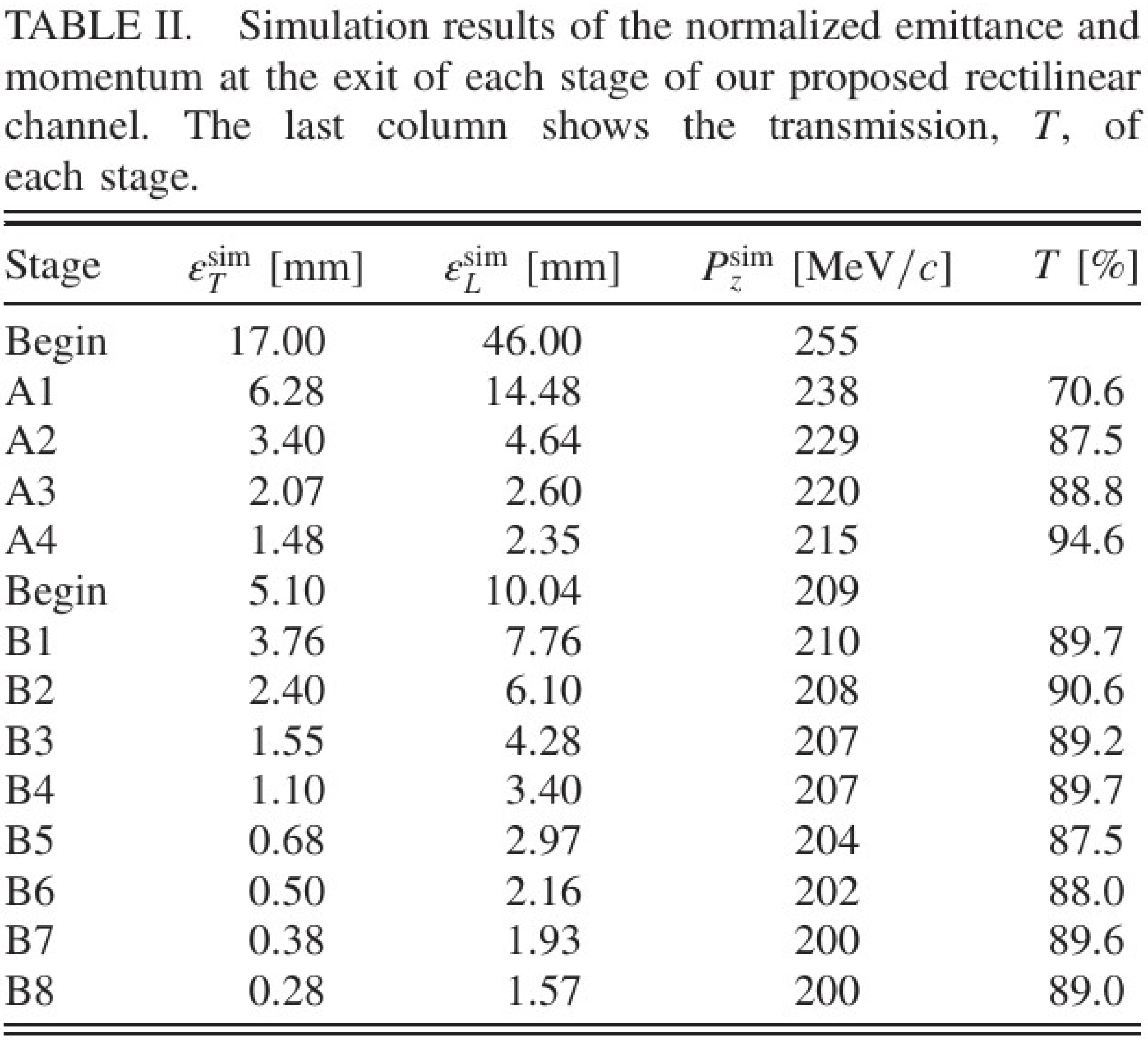
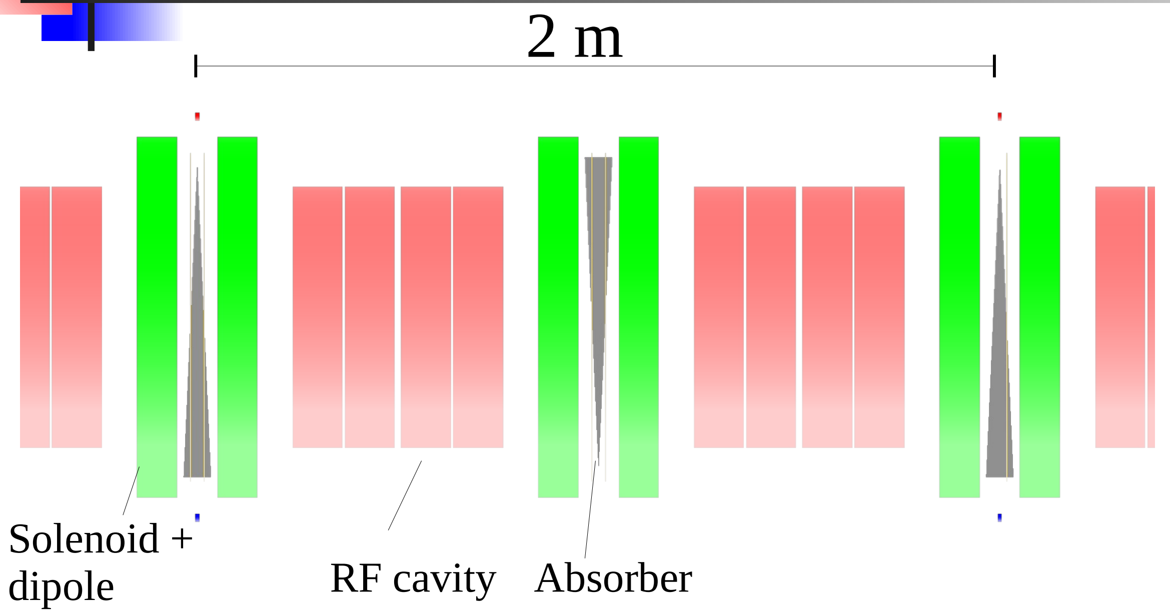


TABLE II. Simulation results of the normalized emittance and momentum at the exit of each stage of our proposed rectilinear channel. The last column shows the transmission, T, of each stage.

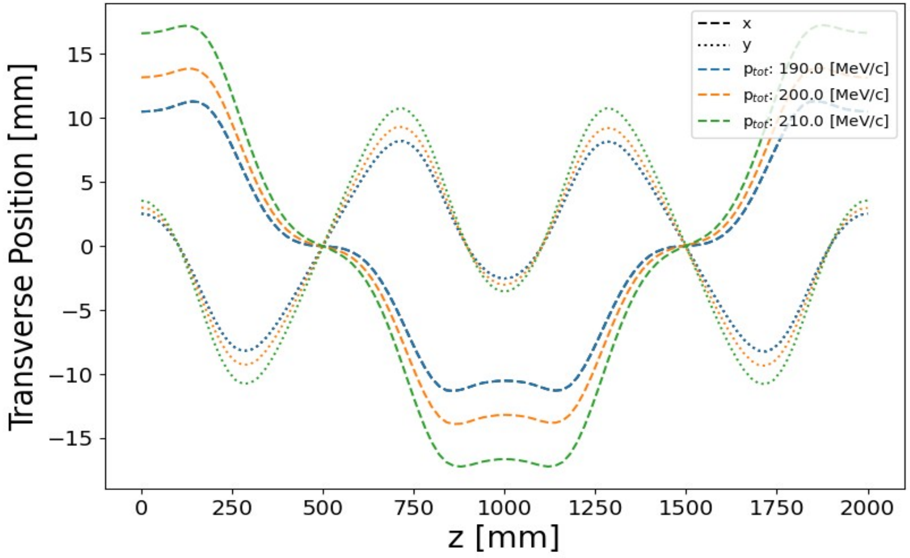
Stage	$\varepsilon_T^{\mathrm{sim}}$ [mm]	$\varepsilon_L^{\mathrm{sim}}$ [mm]	P_z^{sim} [MeV/c]	T [%]
Begin	17.00	46.00	255	
A1	6.28	14.48	238	70.6
A2	3.40	4.64	229	87.5
A3	2.07	2.60	220	88.8
A4	1.48	2.35	215	94.6
Begin	5.10	10.04	209	
B1	3.76	7.76	210	89.7
B2	2.40	6.10	208	90.6
B3	1.55	4.28	207	89.2
B4	1.10	3.40	207	89.7
B5	0.68	2.97	204	87.5
B6	0.50	2.16	202	88.0
B7	0.38	1.93	200	89.6
B8	0.28	1.57	200	89.0

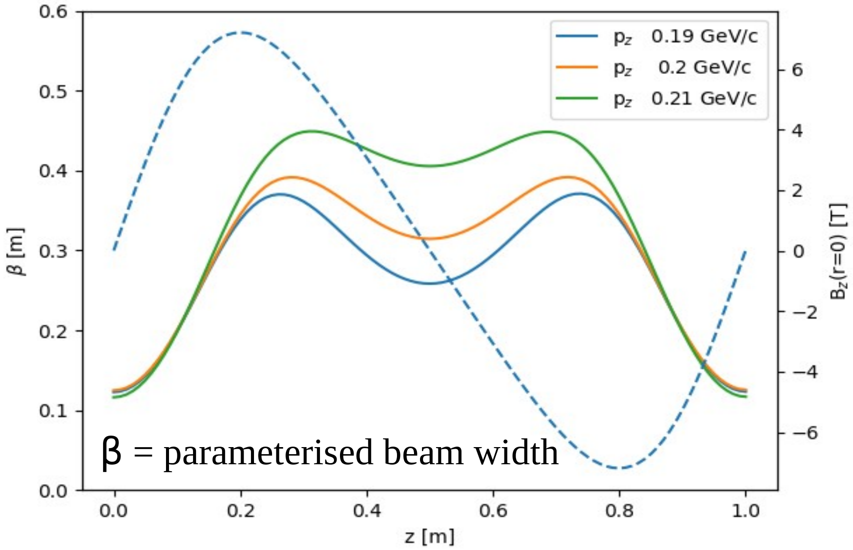
Bunch merge →

Preliminary Cooling Cell Concept



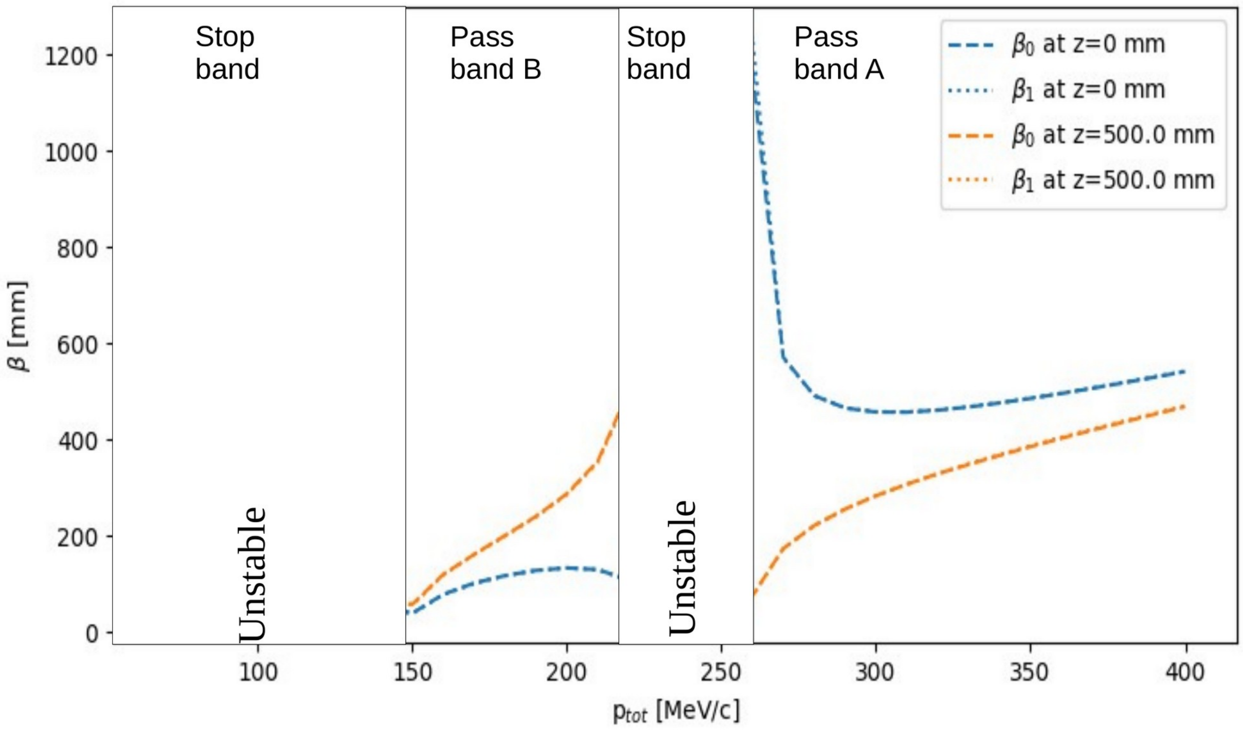
Cooling System	
Cell length	2 m
Peak solenoid field on-axis	7.2 T
Dipole field	0.2 T
Dipole length	0.1 m
RF real estate gradient	22 MV/m
RF nominal phase	20°
RF frequency	704 MHz
Wedge thickness on-axis	0.0342 m
Wedge apex angle	5°
Wedge material	LiH





β = parameterised beam width

Focusing

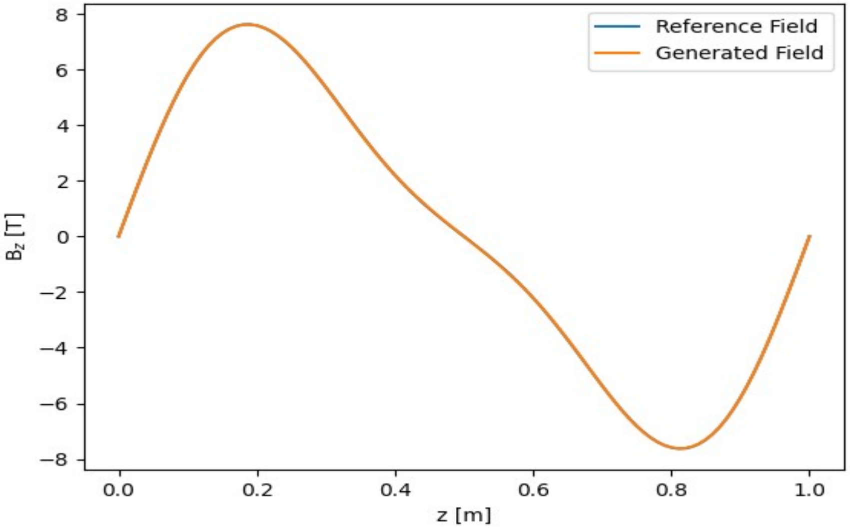


- Two types of lattice
  - "A-type" work in pass band A
  - "B-type" work in pass band B

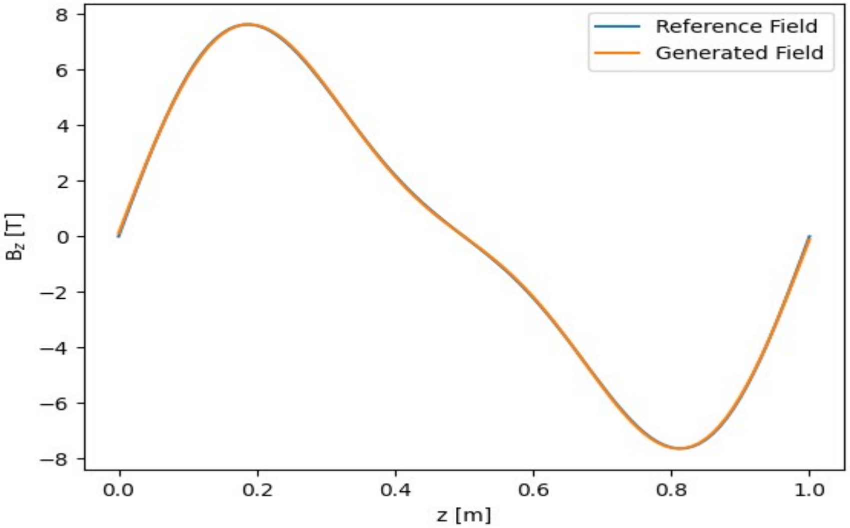
Movies

Rectilinear – Acceptance

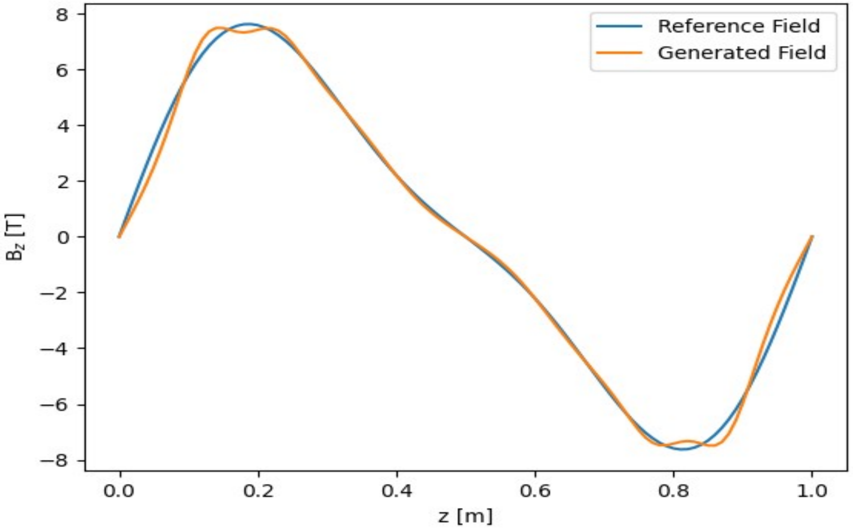
Inner radius 0.2 m



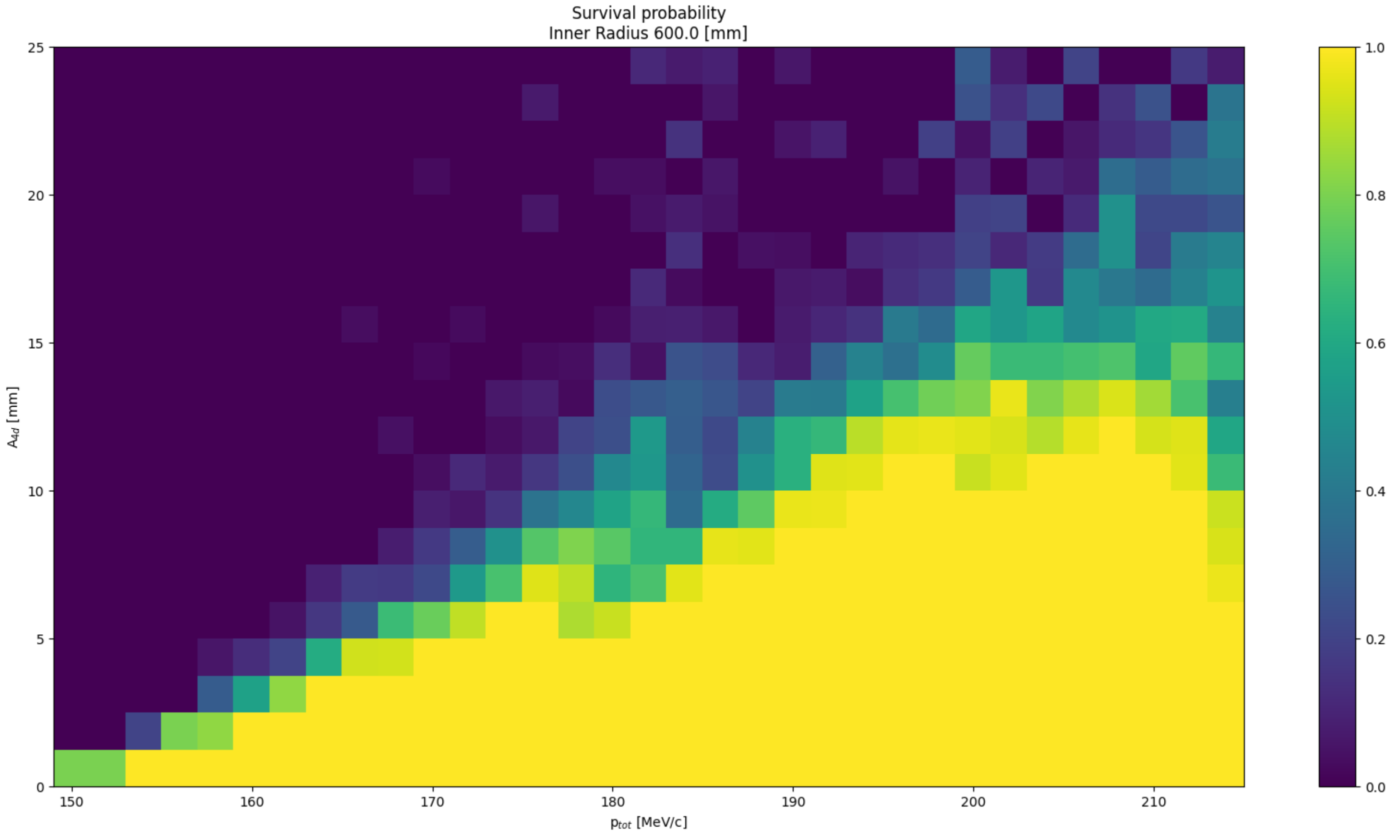
Inner radius 0.6 m



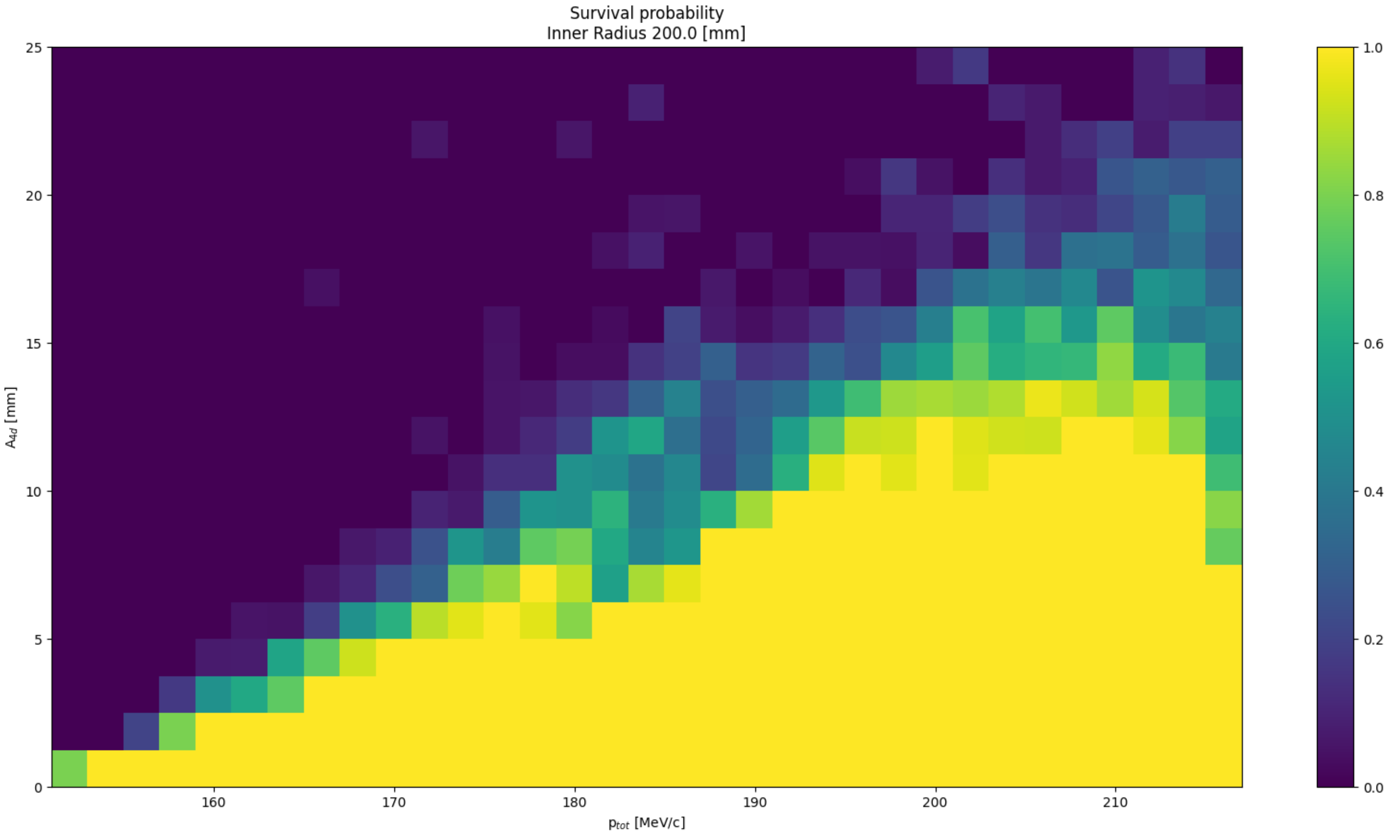
Inner radius 0.05 m



Rectilinear – Acceptance (600 mm)

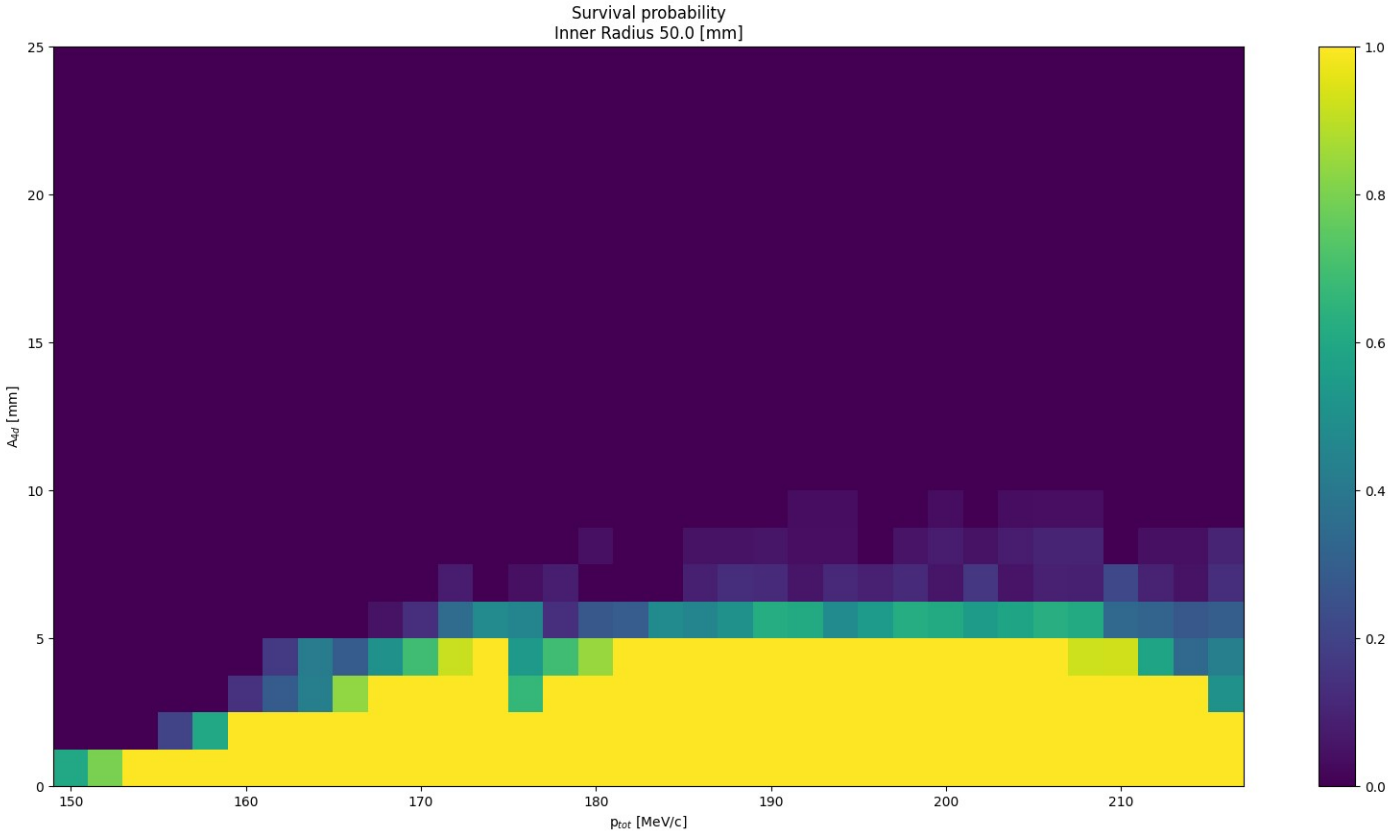


Rectilinear – Acceptance (200 mm)

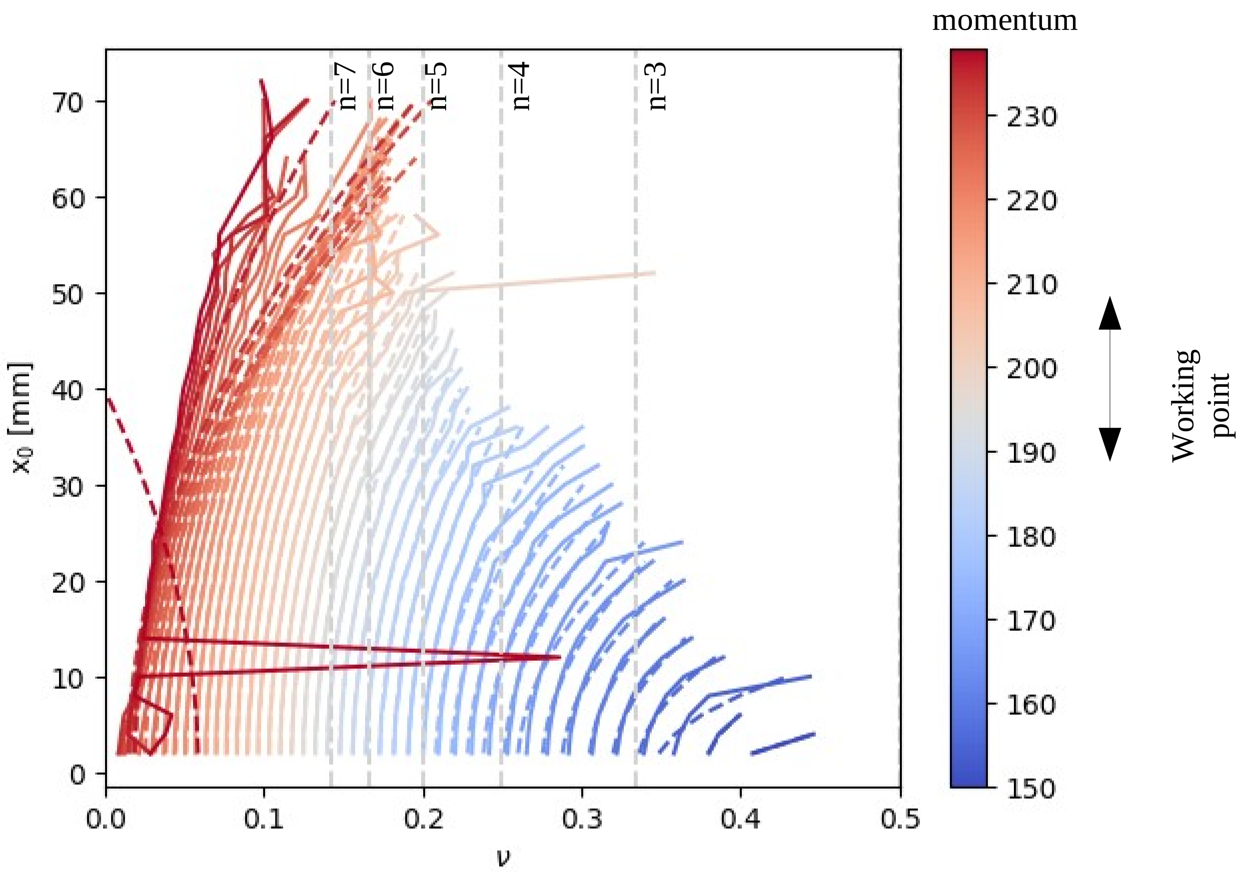


Science & Technology Facilities Council
ISIS Neutron and Muon Source

Rectilinear – Acceptance (50 mm)

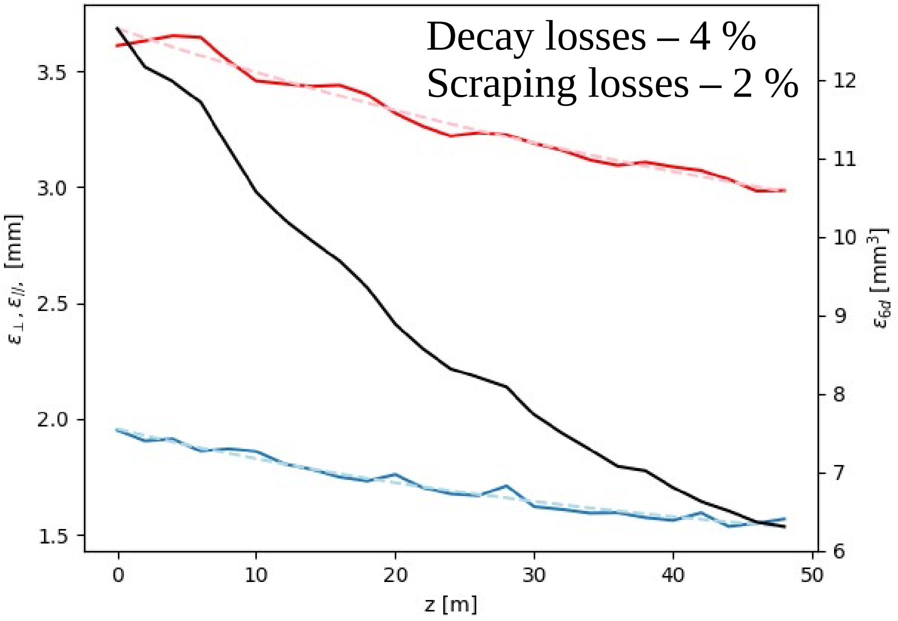


Detuning – vs momentum

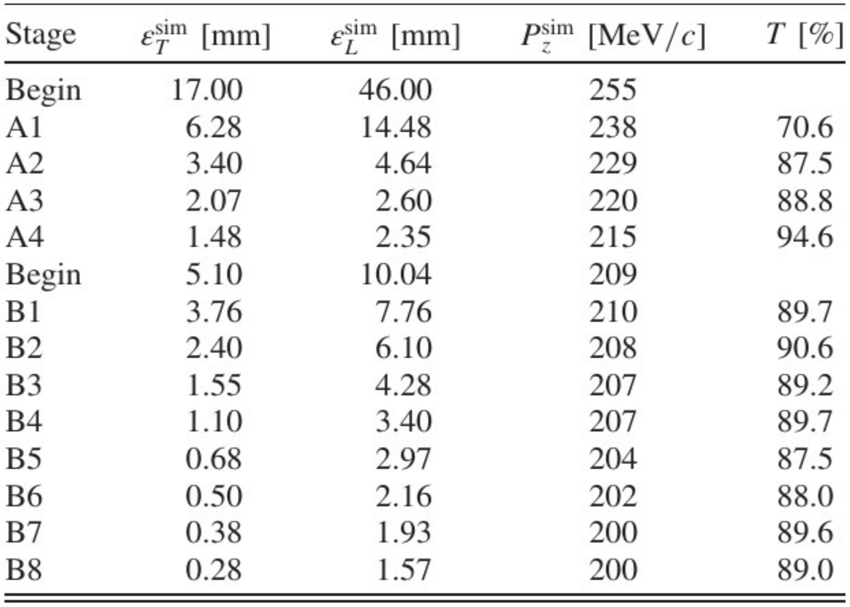


- Looks like n=6 resonance is driving loss in the high acceptance region

Performance – sample lattice



Decay losses – 4 %
Scraping losses – 2 %



Stage	$\varepsilon_T^{\text{sim}}$ [mm]	$\varepsilon_L^{\text{sim}}$ [mm]	P_z^{sim} [MeV/c]	T [%]
Begin	17.00	46.00	255	
A1	6.28	14.48	238	70.6
A2	3.40	4.64	229	87.5
A3	2.07	2.60	220	88.8
A4	1.48	2.35	215	94.6
Begin	5.10	10.04	209	
B1	3.76	7.76	210	89.7
B2	2.40	6.10	208	90.6
B3	1.55	4.28	207	89.2
B4	1.10	3.40	207	89.7
B5	0.68	2.97	204	87.5
B6	0.50	2.16	202	88.0
B7	0.38	1.93	200	89.6
B8	0.28	1.57	200	89.0
BR in	1.95	3.61	200	-
BR out	1.57	2.99	200	94 %

- Performance – okay compared to Stratakis lattices
  - Better transmission
  - Worse emittance reduction
- Optimisation continues
  - Acceptance
  - lH2

Technical challenges

- Beam loading
- Absorber heating
    - LH2 may be an issue
- Radiation loads on SC magnets
    - Minimise scraping losses
- Magnet limits + integration issues
    - What is the shortest lattice and highest field?
- Magnet vs RF

Where Next?

- Promising start
  - Happy with linear optics
  - Can reproduce reasonably optimised lattice
  - Would like better understanding of DA
  - Would like to draw on Diktys’s optimisation more
- Need to take a look at possible problems/technical issues
  - Better to hit the “surprises” early on and manage appropriately